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16. Abstract <p>The 25 MeV deuteron beam from the NASA variable energy cyclotron incident on a thick beryllium target will deliver a tissue neutron dose rate of 2.14 rad/<math>\mu</math>A-min at a source to skin distance of 125 cm. A neutron survey of the existing hallways with various shielding configurations made during operation of the horizontal neutron delivery system indicates that minimal amounts of additional neutron shielding material are required to provide a low level radiation environment within a self-contained neutron therapy control station. Measurements also indicate that the primary neutron distribution delivered by a planned vertical delivery system will be minimally perturbed by neutrons backscattered from the floor.</p>					
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A PRELIMINARY AREA SURVEY OF NEUTRON RADIATION LEVELS ASSOCIATED  
WITH THE NASA VARIABLE ENERGY CYCLOTRON HORIZONTAL  
NEUTRON DELIVERY SYSTEM

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INTRODUCTION

The preliminary neutron radiation levels reported herein were needed as a guide in modifications of the existing building and cyclotron beam transport system to allow The Cleveland Clinic Foundation to perform neutron cancer therapy with the NASA neutron delivery systems. In support of this medical application The Cleveland Clinic Foundation plans to provide a building above grade for patient preparation, office, and conference rooms with elevator access to a therapy treatment control station and the treatment room itself. This arrangement will allow The Cleveland Clinic Foundation personnel to control access to the treatment room during therapy operations.

The primary purpose of this report is to provide (1) engineering data needed to determine the shielding requirements necessary to reduce the neutron dose rate in the therapy control station to a level of 2.5 mrem/hr and (2) information on the neutron albedo to be expected at the planned vertical neutron delivery port.

CONTROL STATION SHIELDING

Figure 1 is a plan view of the existing hallways, work area, and beam room of the NASA cyclotron facility. (We will henceforth refer to the beam room as the treatment room.) The horizontal beam delivery system used in these tests is shown in this drawing. Boxes of paraffin were used to simulate the neutron shield-collimator which at the time of these tests was still being fabricated. A cross section of the paraffin collimator is shown in figure 2. The boxes formed a cube roughly 4 feet on a side. The beryllium target was situated near the center of the cube. Neutrons emerged from this shield along the deuteron beam axis through a collimator constructed of Pb and borated polyethylene. The exit dimensions of this port were 10 cm high by 7.5 cm wide.

Figure 3 is a conceptual view in cross section through the horizontal neutron delivery system and the planned vertical neutron delivery system.



Table I lists the neutron and gamma ray dose rates observed at the positions indicated in figure 1. These dose rates were observed with 20  $\mu$ A of 25 MeV deuterons incident on the thick beryllium target located within the paraffin shield-collimator and shown in figure 2. A "Snoopy" neutron radiation survey meter was used to measure neutron radiation levels. "Snoopy" has a nearly tissue equivalent response for neutrons up to 10 MeV. Our forward-directed neutron spectrum has an average energy of about 10 MeV. At the points at which measurements were made the neutrons have a much lower average energy due to (1) moderation of the target neutron in the paraffin collimator and (2) further reduction in neutron energy due to the multiple scattering process necessary to produce neutrons which could arrive at the points at which these measurements were made. A "Cutie Pie" gamma radiation survey meter was used in the gamma ray measurements. Both radiation detectors were calibrated prior to use.

At the center of the hall outside the entrance to the planned therapy control station (position D, fig. 1) the neutron dose rate was 1400 mrem/hr. Within the therapy control station the specified neutron dose rate should be less than 2.5 mrem/hr. To obtain a measurement of the thickness of the neutron shielding door required to provide the specified neutron dose rate within the therapy control station the control station and its entrance were simulated by a concrete block house constructed at position C in figure 1. The block house is shown in detail in figure 4. "Snoopy" was placed within the block house. The shielding thickness above, below, behind, and on the sides of the "Snoopy" was great enough to simulate infinite neutron shielding in those directions. Various thicknesses of polyethylene, paraffin, or concrete were then placed across the entrance to the block house and the neutron dose rates measured. Figure 5 is a plot of the observed neutron dose rates as a function of absorber thickness again referred to 20  $\mu$ A of 25 MeV deuterons on a thick beryllium target. Five inches of polyethylene or 14 inches of concrete will provide adequate shielding based on this model.

This model does not completely simulate the therapy control station since the "doors" are dramatically different in size. The door to the therapy control station will be roughly 5 feet wide by 7 feet high whereas the opening into the simulated therapy control station was 8 inches high by 12 inches wide. The simulated control station allows one to measure a nearly good geometry attenuation coefficient for the various materials used as "doors." In the actual situation the apparent absorption of the therapy control room door will be less because the large door acts more like a poor geometry attenuator. Poor geometry attenuation coefficients are no less than one half the good geometry attenuation coefficients. For this reason we recommend that the therapy control room door be constructed of 8 inches of benelex. Benelex is a

pressed wood material which on a hydrogen content basis is very nearly equivalent to polyethylene as a neutron absorber.

One important note of caution in the application of these shielding results is in order; namely, the shielding door shown in figure 1 should not see neutrons which can arrive directly from the horizontal beam neutron collimator since these neutrons could once scatter into the therapy control room and thereby greatly increase the dose rate above that measured in these tests.

If the neutron dose rates observed in the planned therapy control room after installation of the actual horizontal neutron collimator are greater than reported herein, additional shielding can be interposed between the collimator and the control room entrance.

As a part of these measurements a simple 8 inch thick concrete block wall 6 feet high and 4.5 feet wide and butted against the north wall of the hall was constructed at point E in figure 1. This reduced the dose rate at point D by a factor of 2. Additional measurements indicated that no further reduction in dose rate at D could be obtained with the wall at point E even if this temporary wall was thickened or extended to the south wall of the hall. This indicated that most of the remaining dose at point D came from neutrons passing over the top of the 6 foot wall. Estimates based on solid angle considerations would indicate a minimum reduction in neutron dose rate at point D by a factor of 4 if a wall 8 inches thick and extended to the hallway ceiling were constructed across the hallway at point E. A 7- by 3.5-foot opening in this wall would provide access to the therapy room.

#### NEUTRON ALBEDO

The following results provide information on neutron albedo at the planned vertical neutron delivery port. The Cleveland Clinic Foundation personnel must evaluate these results and determine whether a neutron beam catcher is necessary below the vertical delivery system.

Tests were conducted using the previously described horizontal neutron delivery system to determine the neutron/ $\gamma$  ray albedo expected to exist at the patient position in the planned vertical neutron delivery system. These tests were necessary due to the proximity of the floor to the patient (~5 ft = 150 cm). A 1 cc tissue equivalent plastic ion chamber and a 2 cc magnesium ion chamber were exposed to the horizontal neutron beam at a beryllium target to chamber distance of 125 cm or in the same plane but 25 cm off the beam axis. The  $\gamma$  ray/neutron dose rates can be determined using these two chambers as outlined in reference 1. For these measurements a simulated floor consisting of concrete blocks 4 feet by 4 feet by 16 inches was constructed on a movable pallet such that it could be positioned along and normal to the beam axis. Measurements were made with and without the simulated floor in position.

Table II is a compilation of the neutron and  $\gamma$ -ray dose rates observed. The  $\gamma$ -ray dose rates are relatively constant with or without the simulated floor in position. The neutron dose rate in the absence of the simulated floor dropped from 2.14 rad/ $\mu$ A-min on axis to 0.047 rad/ $\mu$ A-min off axis. The off axis dose rate increased to 0.052 rad/ $\mu$ A-min with the simulated floor at 60 cm from the ion chamber plane and to 0.060 rad/ $\mu$ A-min with the simulated floor at 25 cm, increases of 10 and 30 percent, respectively.

The largest field that will be provided at 125 cm from the target is 20 by 20 cm. The field used in these tests was 13 by 10 cm. It is reasonable to assume that albedo effects will be roughly proportional to field size. On this basis one can predict that the simulated floor at 60 and 25 cm from the ion chamber plane would produce a roughly 30 and 100 percent increase in the off axis dose rates for a 20 by 20 cm field. If one plots the expected 20 by 20 cm field increase in off axis dose rates as a function of the reciprocal of the simulated floor to ion chamber plane distance (fig. 6) a nearly linear relation is observed. Based on figure 6 one can predict that in the vertical delivery system the albedo effect due to the floor which is ~150 cm from the plane of interest will produce an increase in off axis neutron dose rate of roughly 0.0055 rad/ $\mu$ A-min (~12 percent). This would seem to indicate that no neutron beam catcher is necessary under these conditions.

The Cleveland Clinic Foundation indicates that in some clinical situations a 30- by 30-cm field would be desirable. Since the largest neutron field that will be provided at a source to skin distance of 125 cm is 20 by 20 cm, the obvious method of obtaining the 30 by 30 cm field is to increase the source to skin distance to 188 cm which will reduce the direct field dose rate by a factor of 2.25 (0.95 rad/ $\mu$ A-min) and would reduce the off axis dose rate by a similar factor (0.014 rad/ $\mu$ A-min). The albedo dose rate, however, will increase due to the decrease in patient to floor distance (decreases from 150 to 92 cm). This decrease in distance would produce an albedo dose rate of 0.0095 rad/ $\mu$ A-min, which is 50 percent of the direct off axis dose rate. To recapitulate: at a source to skin distance of 188 cm using the 20- by 20-cm field collimator the clinician would have available a 30- by 30-cm neutron field. The on-axis neutron dose rate would be 0.95 rad/ $\mu$ A-min and the off-axis dose rate 0.0285 rad/ $\mu$ A-min of which 0.019 rad/ $\mu$ A is direct neutron dose rate of 0.0095 rad/ $\mu$ A-min is albedo neutron dose rate.

#### MOUND SURVEY

A survey of the mound area covering the cyclotron vault and the beam room revealed almost no detectable neutron dose (<0.2 mrem/hr) except at three penetration points into the cyclotron vault area. The conditions during measurements were 40  $\mu$ A of deuteron beam being stopped in the cyclotron vault and 20  $\mu$ A of deuteron beam in the beam room. Directly



over a dry nitrogen gas entrance port to the cyclotron vault we measured 20 mrem/hr, at the exhaust fan ducts located at the southwest corner of the cyclotron vault we measured 1.4 mrem/hr, and at the duct located at the southeast corner 4 mrem/hr. Within a meter of these points, dose rates were less than 0.2 mrem/hr.

### CONCLUSIONS

The NASA 25 MeV deuteron beam on a thick beryllium target will deliver 2.14 rad tissue per  $\mu\text{A}\cdot\text{min}$  at a source to skin distance of 125 cm.

A shielding door of polyethylene 5 inches thick will reduce the dose rate in the therapy control room to less than 2.5 mrem/hr under therapy conditions, i.e., 20  $\mu\text{A}$  of 25 MeV deuterons on a thick beryllium target.

A physical barrier will need to be installed at point B, figure 1, to prevent personnel from entering the hallway leading to the therapy area during therapy, but it does not appear that neutron shielding at this point will be necessary to further reduce the neutron dose rates in the skylight area.

A neutron beam catcher pit beneath the vertical delivery system to reduce neutron albedo is not indicated at a source to skin distance of 125 cm. The Cleveland Clinic Foundation personnel will need to evaluate the data in this report to determine whether a pit need be constructed for other therapy conditions.

A survey of the mound area which presently covers the treatment room and cyclotron vault indicates no neutron radiation hazard presently exists where The Cleveland Clinic Foundation plans to construct the patient access facility. The radiation associated with that portion of the planned vertical beam transport system which will be outside the present therapy room and its impact on the patient access facility is presently being considered. Shielding recommendation will be forthcoming.

### REFERENCE

1. Attix, F. H.; Theus, R. B.; and Rogers, C. C.: Measurements of Dose Components in an  $n - \gamma$  Field. Rep. NRL Prog., Dec. 1974, pp. 7-11.

TABLE I

Station	$D_n$ , mrem/hr	$D_\gamma$ , mR/hr
A	0.4	0.8
B	14	6
C	160	58
D	1 400	Not measured
E	26 000	Not measured

Dose rate at various stations referred to a 20  $\mu$ A, 25 MeV deuteron beam on a thick beryllium target.

TABLE II

$D_n$ , rad/ $\mu$ A-min	$D_\gamma$ , rad/ $\mu$ A-min	Conditions
2.14	0.029	On axis, no wall
.047	.024	25 cm off axis, no wall
.060	.028	25 cm off axis, wall at 25 cm
.052	.024	25 cm off axis, wall at 60 cm

Neutron-gamma ray dose rates as a function of simulated wall position.

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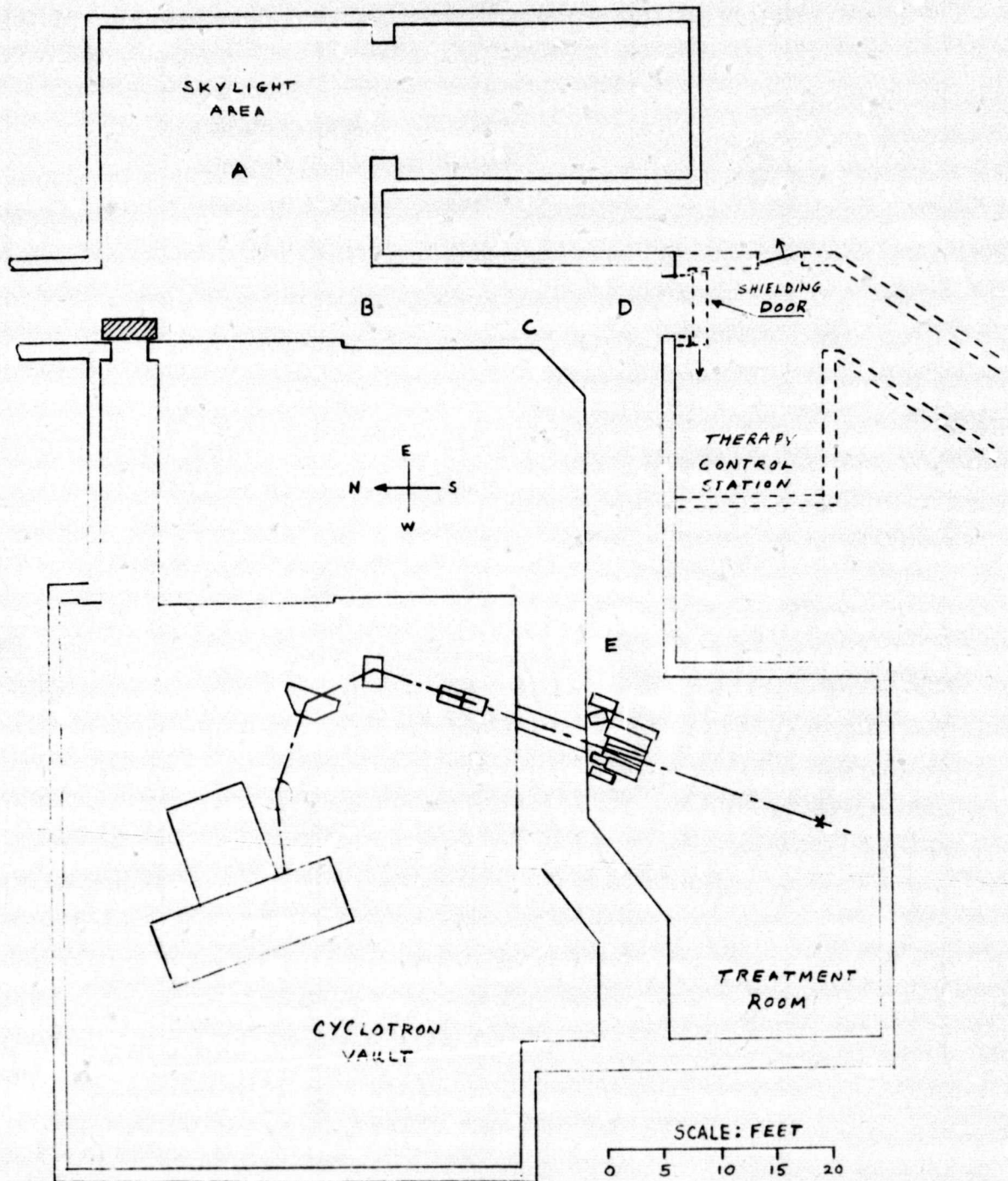


Fig. 1 - Plan view of the NASA cyclotron facility with the planned Cleveland Clinic Foundation therapy control station shown by dashed lines.



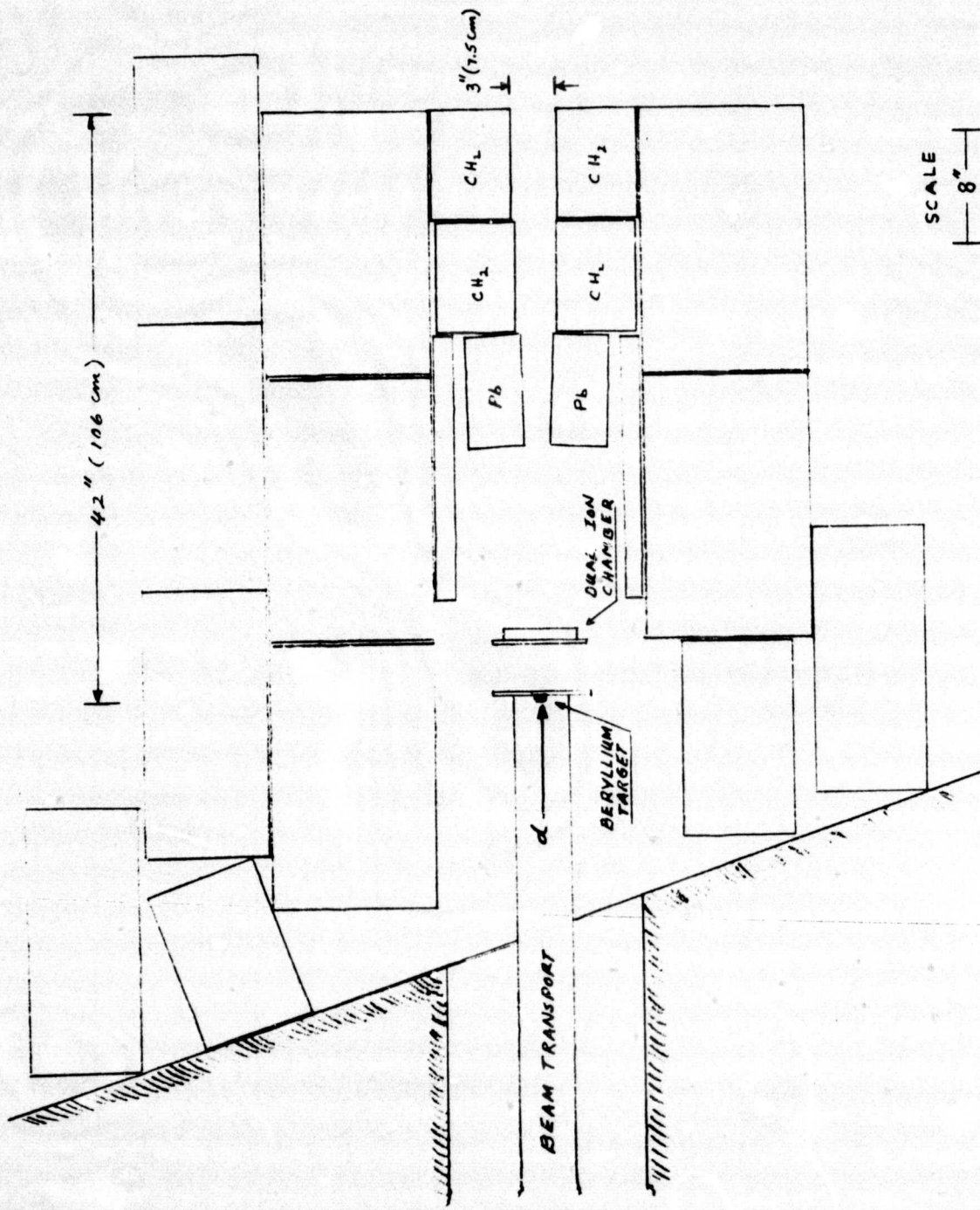


Fig. 2 - Cross section of the collimator used in these tests.

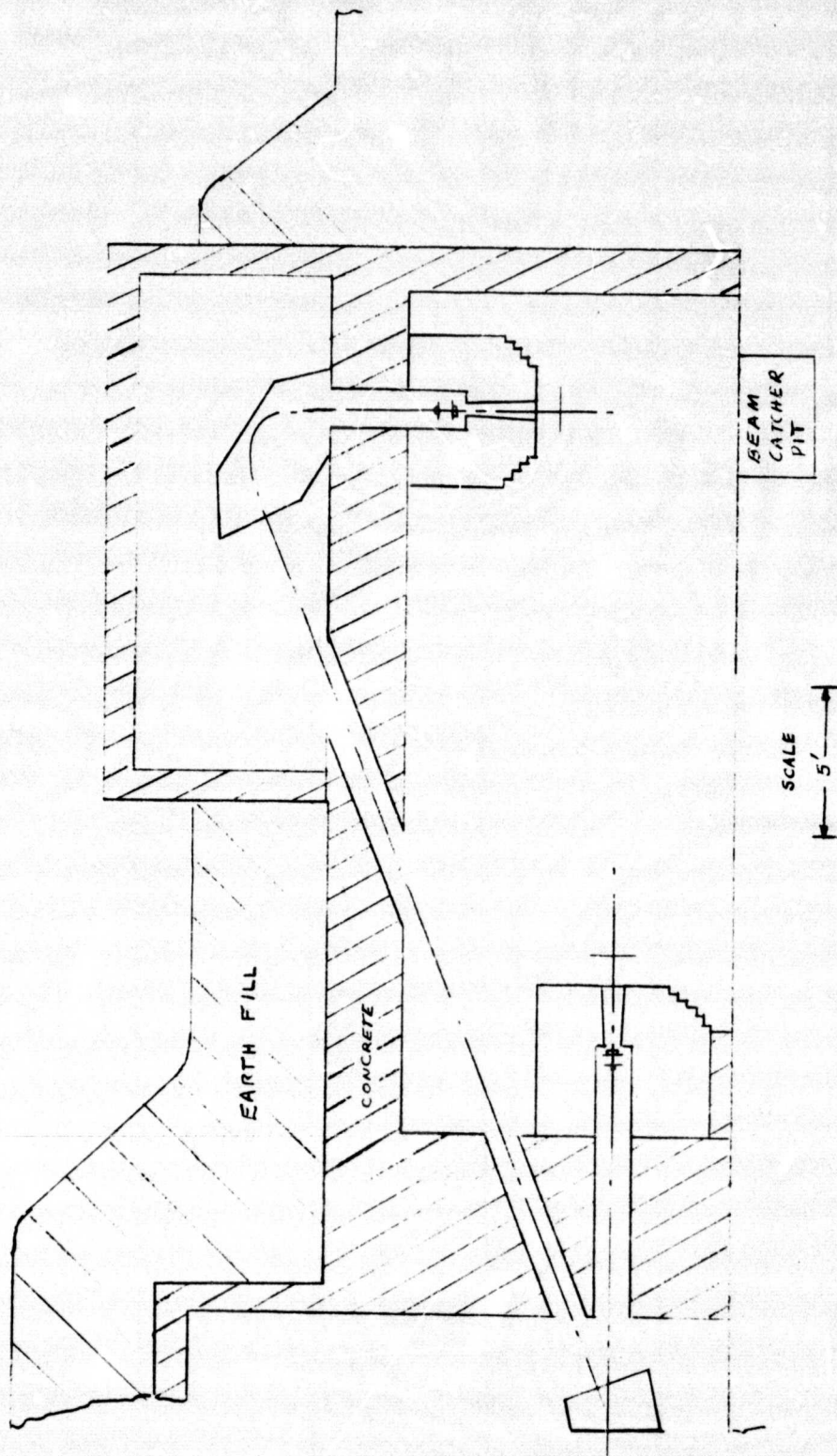


Fig. 3 - Section through the beam transport system center line showing horizontal and planned vertical neutron delivery systems.



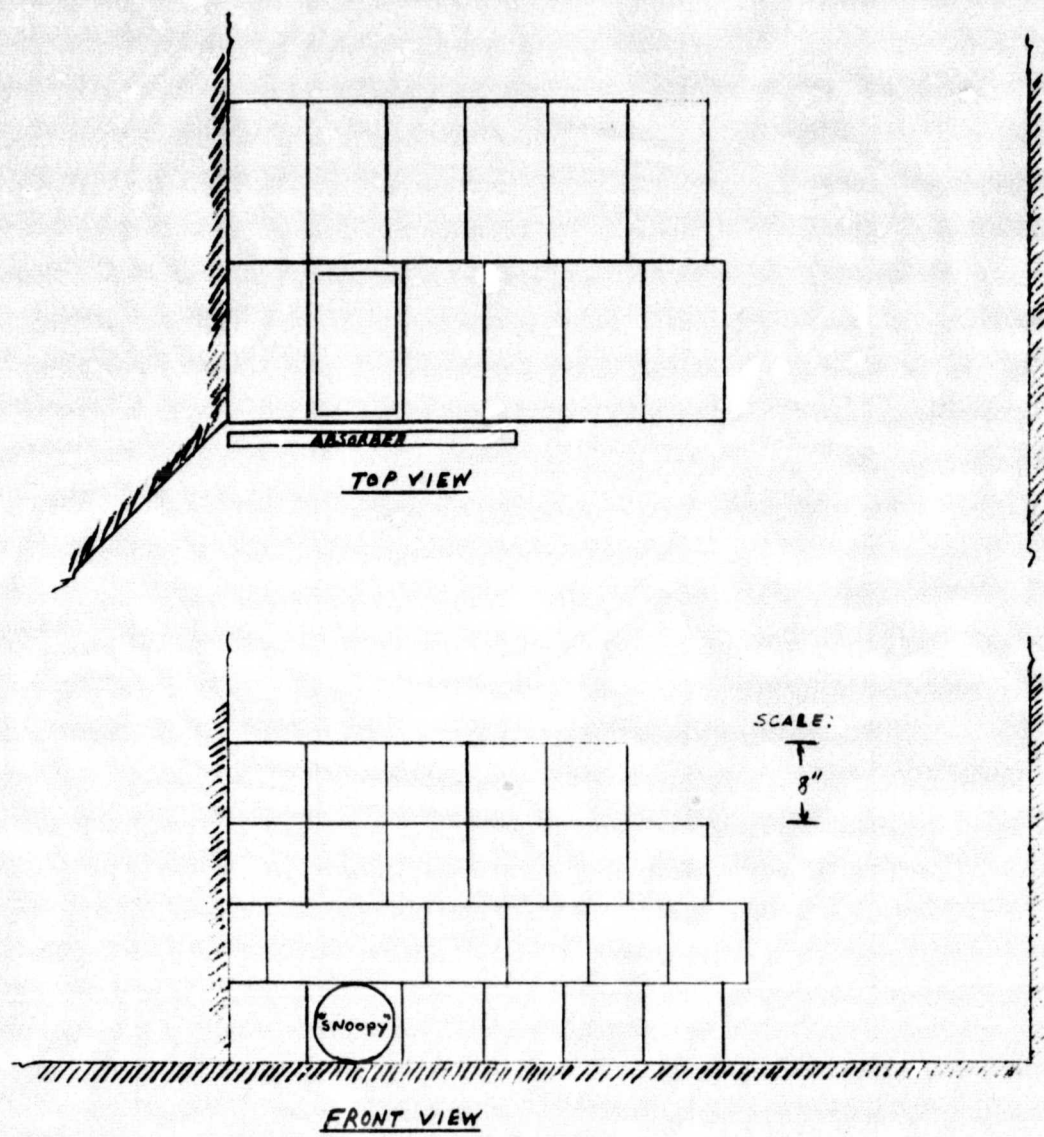


Fig. 4 - Concrete block house used to simulate therapy control room entrance.

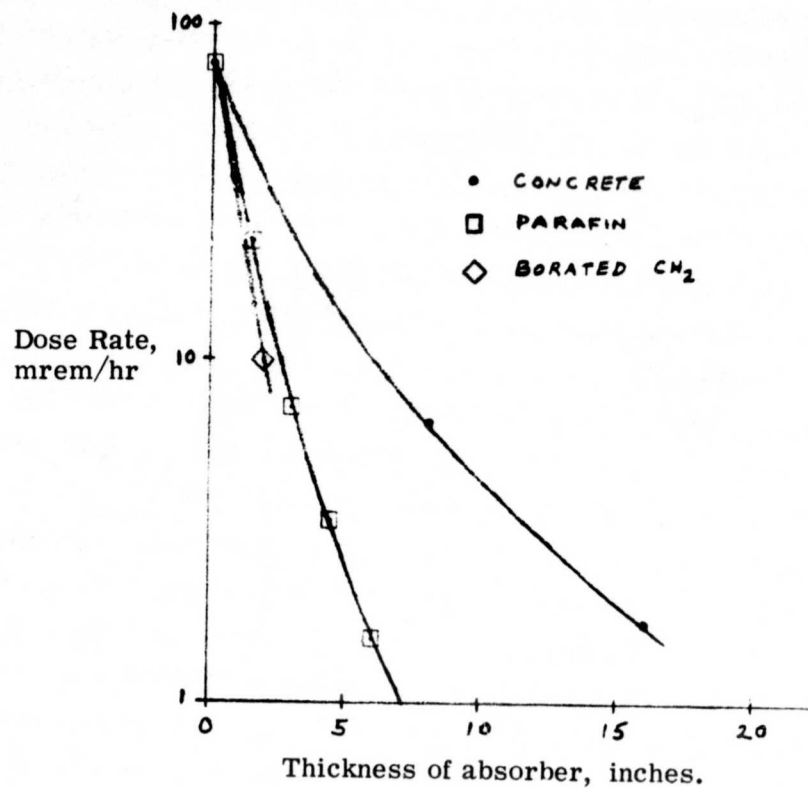


Fig. 5 - Dose rates within a simulated therapy control station for doors of various materials.

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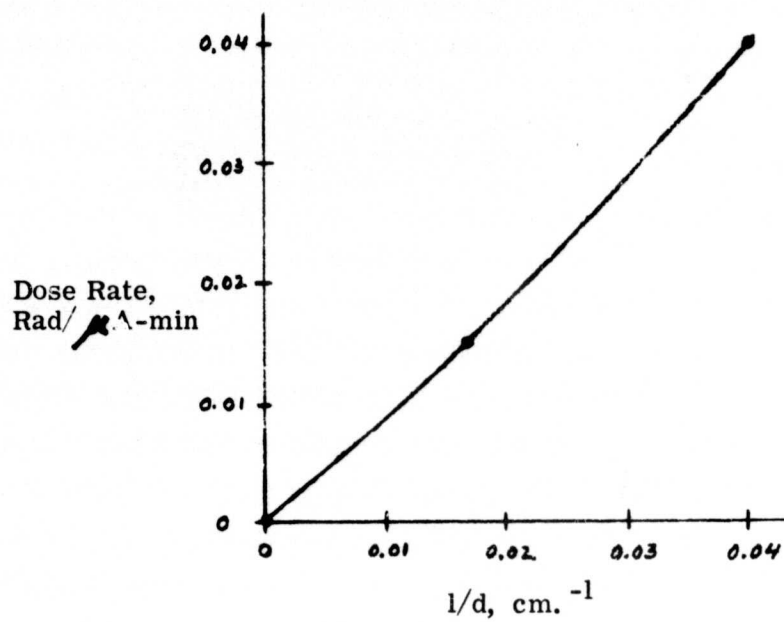


Fig. 6 - Increase in off axis dose rate for a 20 cm. by 20 cm. neutron field as a function of floor to measurement plane distance  $d$ .